# Experimental Investigation of Tribological Properties of $Cu/Al_2O_3/TiO_2$ composites

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

**Bachelor of Technology**

(Mechanical Engineering)

by

**SANJOG BARIK**

**(Roll Number: 108ME028)**

**BRIJESH KUMAR SINGH**

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**DEPARTMENT OF MECHANICAL ENGINEERING**

**NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA**

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*Under the supervision of*

**Prof. S.C. Mohanty**


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# CERTIFICATE

This is to certify that the thesis entitled "**Experimental Investigation of Tribological Properties of Cu/$Al_2O_3$ / $TiO_2$ composites "** submitted by **Sanjog Barik (Roll Number: 108ME028) and Brijesh Kumar Singh(Roll Number: 108ME052)** in partial fulfilllment of the requirements for the award of ***Bachelor of Technology*** in the department of Mechanical Engineering, National Institute of Technology, Rourkela is an authentic work carried out under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted elsewhere for the award of any degree.

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**Associate Professor**
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National Institute of Technology
Rourkela-769008

# A C K N O W L E D G E M E N T

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# *Abstract*

*Tribological properties play an important role in day to day life. Tribology includes study of friction, wear and lubrication. Tribology comes in picture when there is relative motion between two surfaces in contact. When there is relative motion between two surfaces in contact, there is loss of material rubbing each other. In order to minimize friction and wear, we can choose suitable lubricant. This project aims at fabricating pin on disc machine, preparing three composites made from copper, alumina and titanium dioxide by powder metallurgy process and conducting wear test for the three composites by help of pin on disc machine. By conducting the wear test, graphs are plotted between wear rate and sliding velocity. From the results obtained, effect of sliding velocity and composition of composites on wear rate of the three specimens were analysed.This investigation will help us to improve the tribological behavior of rubbing surfaces by varying their composition. The details of experimentation and analysis are given in the following context.*

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# Chapter 1

## INTRODUCTION

With the increasing demand of the hour, many new techniques to maintain economic production are coming out. Study of tribological behavior of materials is one such method. Tribology basically includes wear, friction and lubrication properties of a material. Also Tribological studies are carried out for ceramic composites to measure their mechanical properties.

Composite materials reinforced with ceramic particles/fibers (e.g. alumina) are extensively used in the applications where tribological properties (wear rate, coefficient of friction, lubrication) are important. Metallic ceramics, where the base material is either a metal or a metallic oxide, exhibit extraordinary wear resistance and are used in places where there is a requirement for high wear resistance, e.g., gears, bearings etc.

## 1.1 Study of various materials to be used

Alumina is considered to be one of the most important metallic oxide ceramics because of its possessing excellent mechanical properties such as excellent wear resistance, hardness etc., but they have a relatively low strength and fracture toughness. Aluminum alloys are being widely used as matrix material for fabrication of metal matrix composites reinforced with alumina particles. Engine pistons, engine blocks and other automotive and aircraft parts, operating under severe friction conditions are fabricated from alumina reinforced aluminum-matrix composites. The disadvantage of alumina reinforced aluminum matrix composites are relatively high coefficient of friction and high wear rate. Highly pure alumina ceramics is ideal for an environment where resistance to wear and corrosive substances are used.

Alumina ceramics have excellent thermal stability, which means that they are widely used in areas where there is a requirement for resistance to high temperatures. Alumina ceramic is the choice for alumina wear parts. The proven wear-resistance of alumina wear parts make them perfect for the manufacture of wear-resistant components.

Titanium dioxide is another important metallic ceramic, but it has poor mechanical properties. A combination of alumina and titanium gives a better ceramic composite which can give better wear resistance than pure alumina. Our present aim is to test the mixture of various composition of alumina and titanium in a copper base and test it for its different properties , to compare it with pure alumina.

Copper matrix composites are used widely in sliding electrical contacts of welding electrodes, railway overhead current systems, transfer switches, homopolar machines and other electrical applications. A matrix of copper and alumina gives a very good wear resistance as compared to pure copper metal or pure alumina. Alumina-particle reinforced copper matrix composites have a better wear resistance and better refractory properties than non-reinforced copper.

So our aim is to prepare a matrix of copper, alumina and titanium dioxide with varying compositions of each and then testing it for finding it's wear rate. The ceramic composite will be prepared by mixing all powders with a suitable binder and then pressing it in a die with a suitable load. The ceramic composite which will be formed is a metallic composite, hence it will be an extremely strong ceramic composite and it can also be used in place of alumina, where there is a need for high wear resistance.

## 1.2 Present aim of work

For conducting the experiment, first of all we will be preparing the machine setup. This machine is already available in the market, but our aim is to prepare this machine using some conventional machining methods, so that we can have a machine at a cheap rate. We will be using methods like grinding, drilling, etc to fabricate this simple machine setup. The machine will be measuring the wear rate of the ceramic composite. This machine will be consisting of a high-speed D.C motor connected to a Variable Frequency Drive. The motor will rotate a mild steel disc, which is the rubbing surface for testing of various ceramic composites. The specimen will be in contact with the disc by the help of a flat, which will be made flexible from the other side of the machine base.

# Chapter 2

## LITERATURE SURVEY

In 2006, Deng Jianxin, Cao Tongkun, Ding Zeliang, Liu Jianhua, Sun Junlong and Zhao Jinlong [1] conducted experiment to study the tribological behaviors of hot-pressed $Al_2O_3$/TiC ceramic composites with the additions of $CaF_2$ solid lubricants. Wear rate and friction coefficient of $Al_2O_3$/TiC ceramic composites was found by ring block method. Wear rate and friction coefficient reduced on addition of $CaF_2$ in composite.

In 1997, Q Fang, P Sidky, M.G Hocking [2] did experimental study of erosive wear behaviour of aluminium based composites. Pin on disc machine was used to demonstrate the erosive wear behavior of aluminium based composites.

In 1998, B. Prakash, J. Mukerji and S. Kalia , [3] did experimental investigation of tribological properties of $Al_2O_3$/TiN composites. Friction and wear behavior was studied by conducting the wear test. Wear rate and friction coefficient of the composite was found very low as compared to other materials.

In 2009, M.A. Chowdhury, M.K. Khalil, D.M. Nuruzzaman, M.L. Rahaman [4] conducted experiment to study the effect of sliding speed and normal load on friction and wear property of aluminum disc sliding against stainless steel pin. Friction coefficient decreased but wear rate increased with increase in sliding velocity.

In 2011, Jami Winzer, Ludwig Weiler, Jeanne Pouquet, Jürgen Rödel [5] tested the wear behaviour of a variety of alumina–copper interpenetrating composites as a function ofcopper ligament diameter and volume fraction of copper. The wear mechanisms of copper and alumina were adhesive and abrasive wear respectively. Wear rate increased with increase in copper fraction. Wear rate decreased with increase in copper ligament diameter. Composites with the coarsest copper network showed highest wear resistance, due to the higher heat conductivity and fracture toughness.

# Chapter 3

## FABRICATION AND EXPERIMENTAL PROCEDURE

## 3.1 Fabrication of machine setup

### 3.1.1 Installation of the base:

The base of the machine has to hold a motor, which will rotate a disc used for testing the composite specimen for its tribological properties. The motor has to be connected to a Variable Frequency Drive (VFD) which will regulate the speed of the motor for rotating the disc. The VFD is to be connected to a 3ø power supply. The disc connected to the motor is made up of mild steel and its diameter is 7” with a thickness of ½”. The base is prepared with the help of iron sheets, with dimensions of 36”x18”x18”. The disc is attached with the motor on one side of the base. The base thus prepared is shown in the adjoining figure.

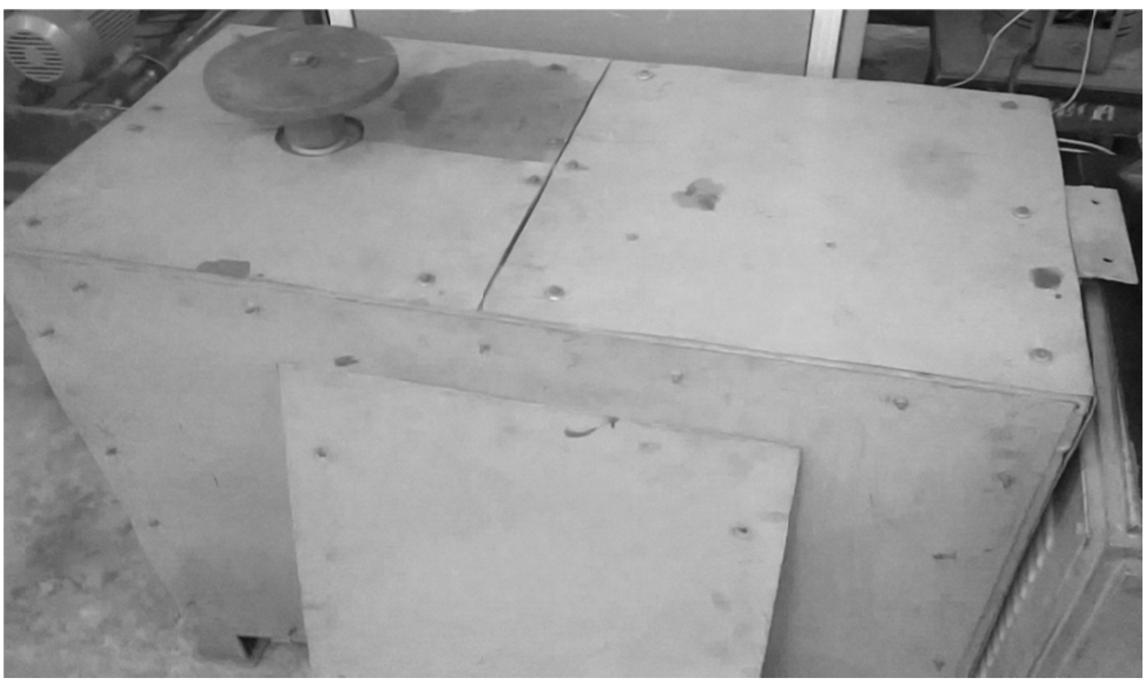

Fig 3.1 Base of the machine setup for conducting the experiment

Fig 3.2  Variable frequency drive

Fig 3.3  High speed motor.

The motor which has been connected, can rotate at a maximum speed of 30000 rpm has been shown in fig 3.3 and the variable frequency drive and the connection to the 3ø power supply has been shown in fig 3.2.

## 3.1.2 Preparation of vice and load cell arrangement:

For preparing the vice, aluminium was being casted in the required shape and the casted material is shown in the figure below. After this the prepared piece was machined and filed to give it a smooth surface, so that it can be used for further operations.

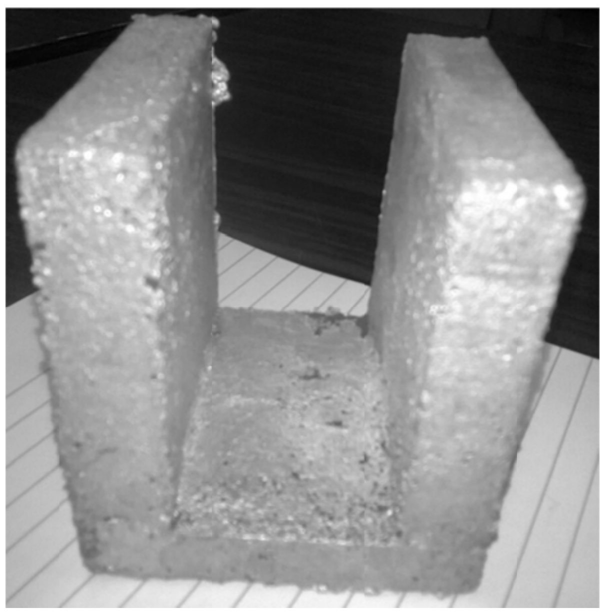

Fig 3.4 Casted vice material

After this, in the machined piece, three holes were drilled on the three surface to fit three bearings to the surfaces. The two bearings at the two lateral surfaces hold a rod of Φ16mm, that is used to hold the specimen-holding flat. The bearing at the bottom holds a rod and flat mechanism to hold it to the base of the machine setup. The prepared vice after drilling and fitting is shown below:

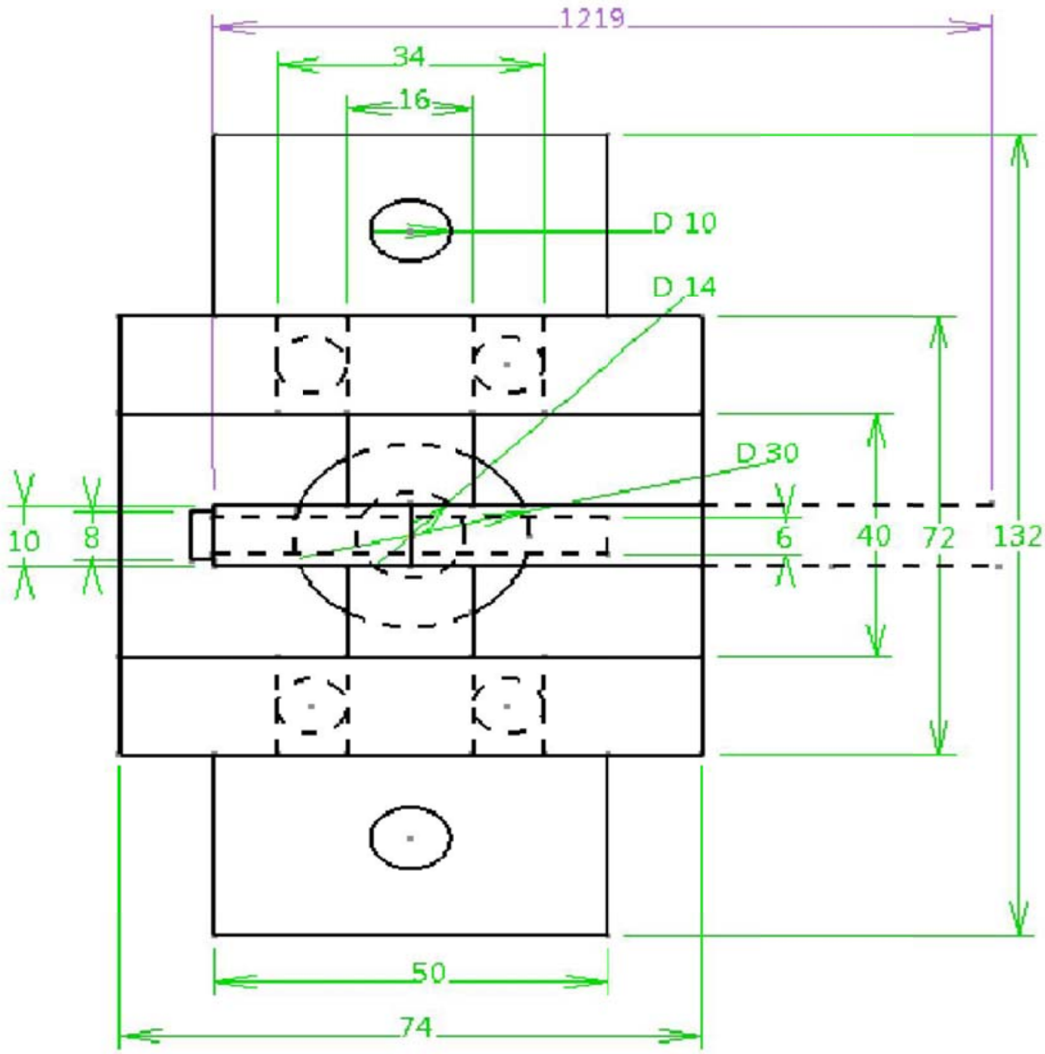


Fig 3.5 Top view of vice and flat assembly

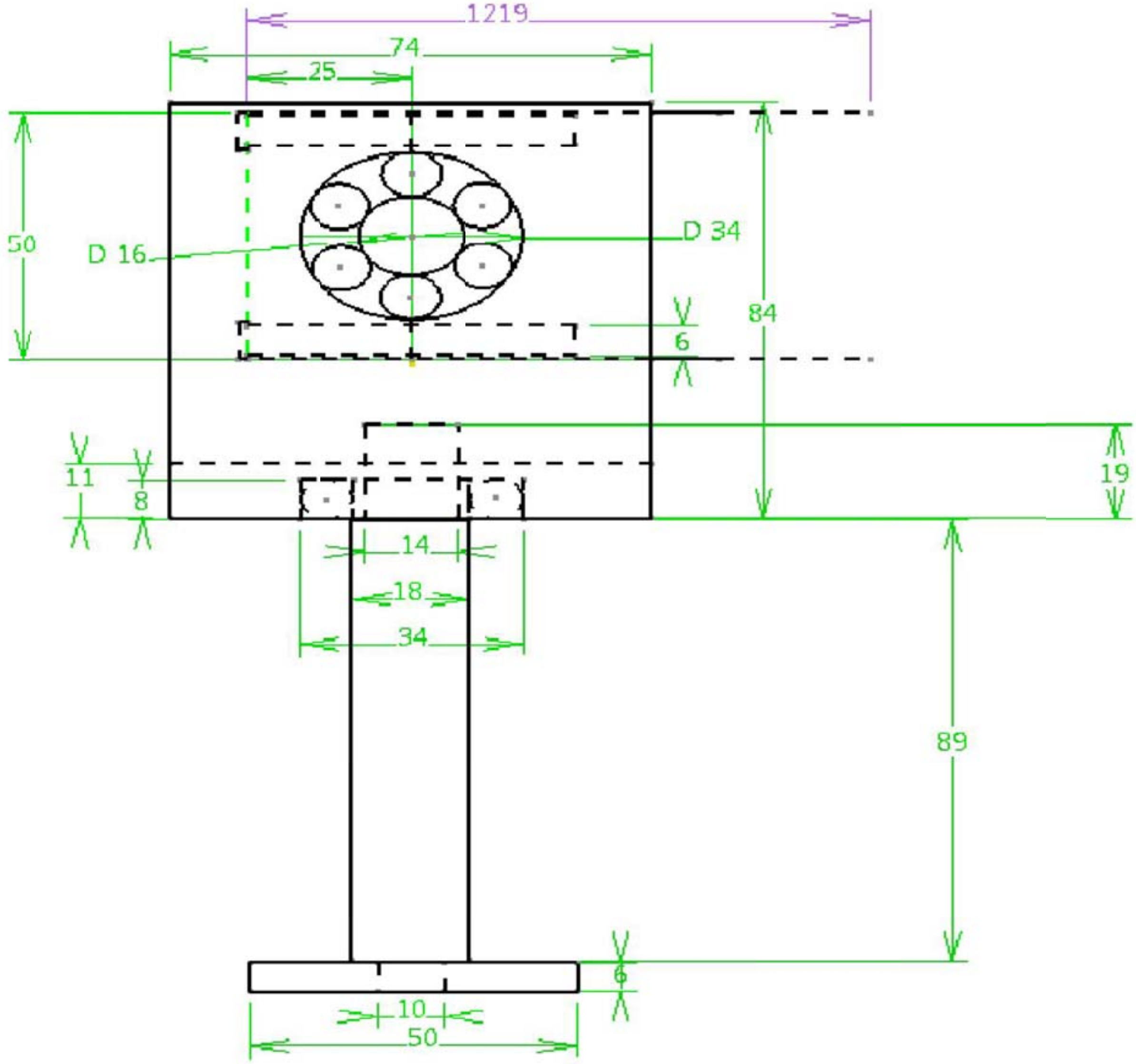


Fig 3.6 Front view of vice and flat assembly

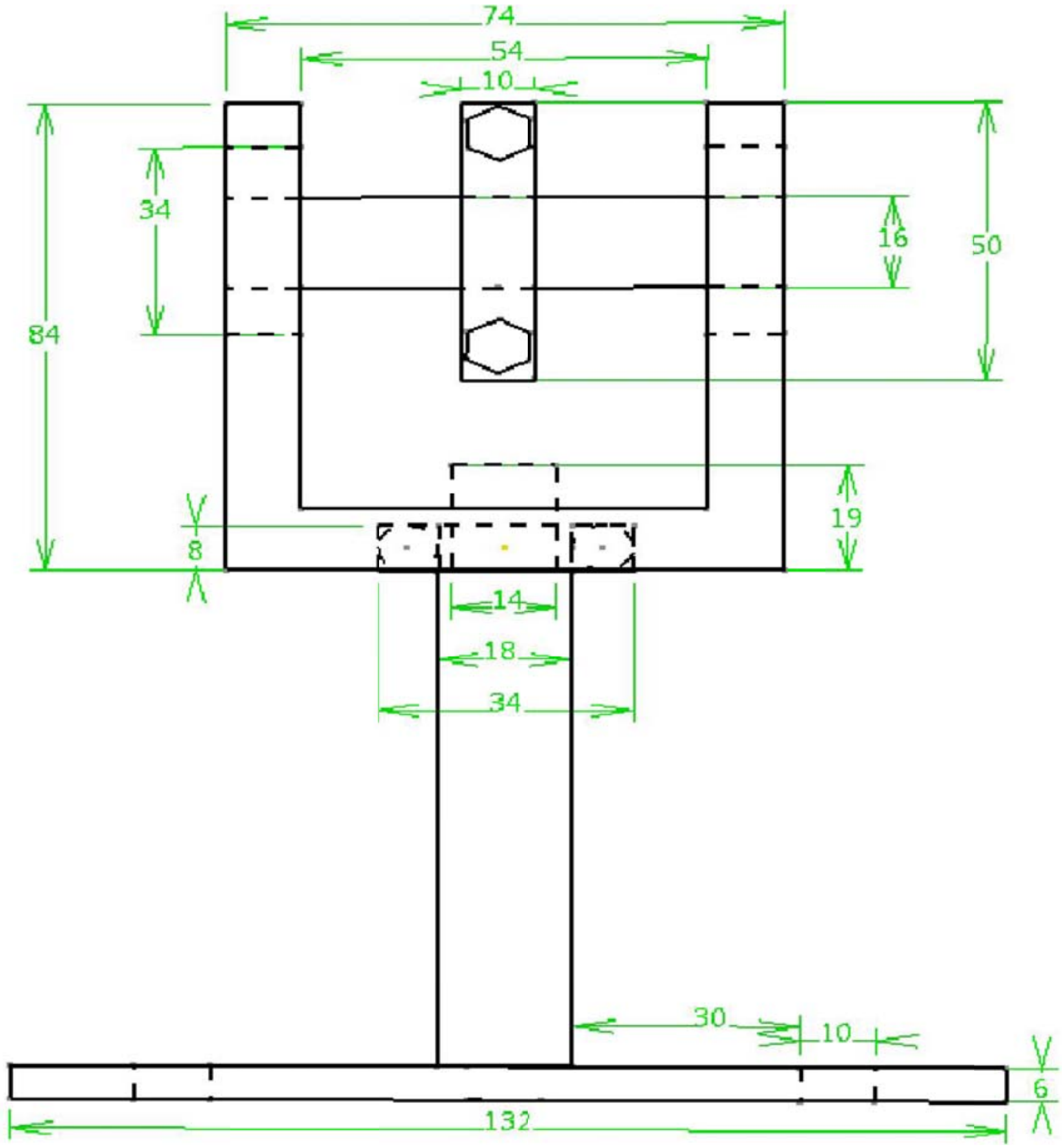


Fig 3.7  Side view of vice and flat assembly

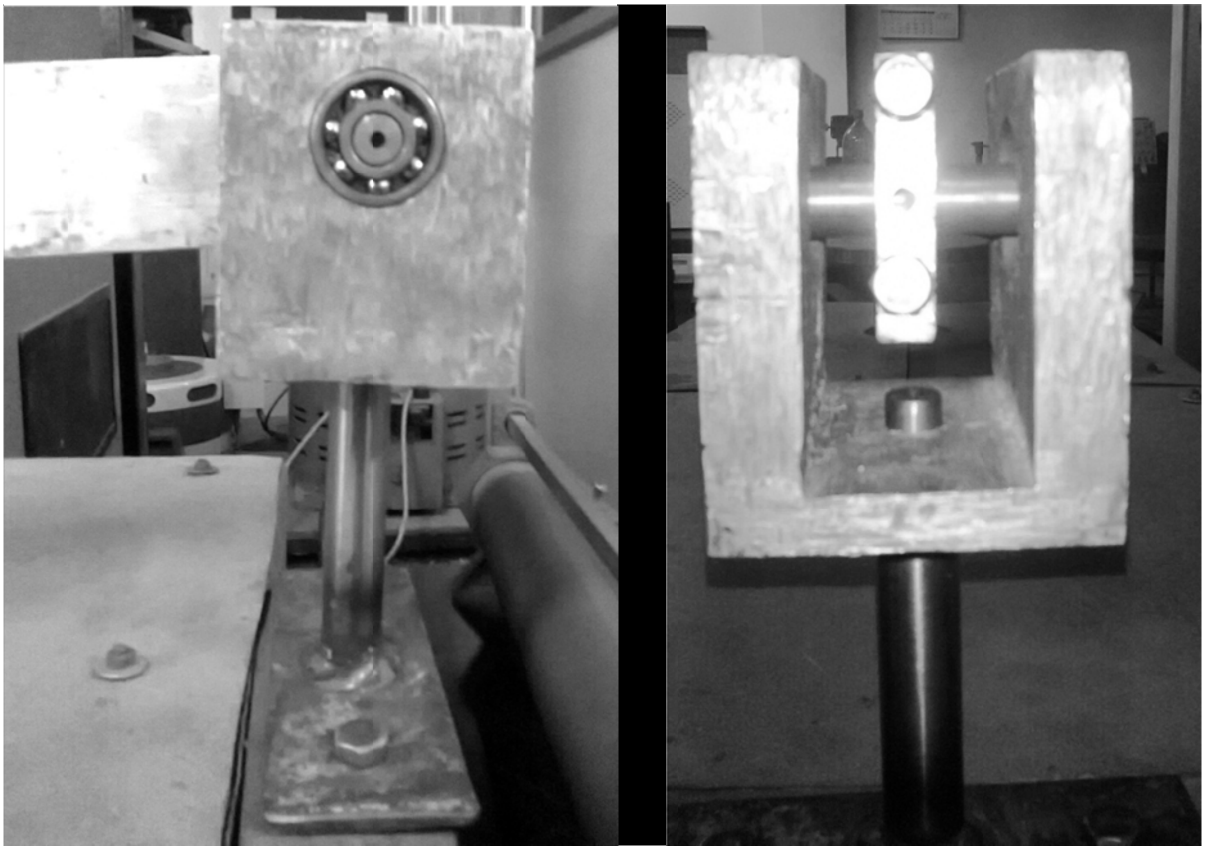

Fig 3.8 Front view and side view of vice and flat arrangement

One side of the flat is attached to the vice for fixing it and the other side is kept free for holding loads on it. It has a slot for holding weights. Above the disc, the bar is having two holes drilled for holding the specimen. The specimen will be held with the help of a 15 mm clamp. In between the clamp and the load slot, a hole is drilled for fixing the Load Cell arrangement. The load cell is being fixed to the bar from the end of the base with the help of 6mm screws. The load cell will be connected to an oscilloscope, which will give readings, from where we can get the wear rate and friction coefficient for the respective specimen. The load cell and the clamp arrangement are shown in the adjoining figures:

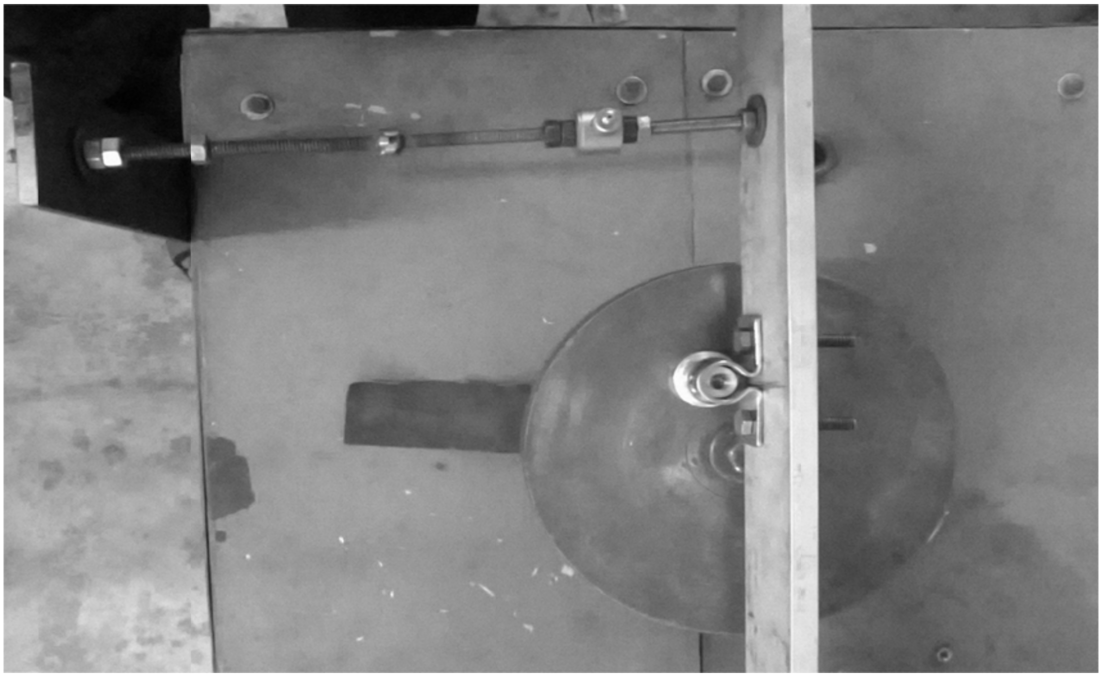

Fig 3.9 Specimen clamping and Load cell arrangement

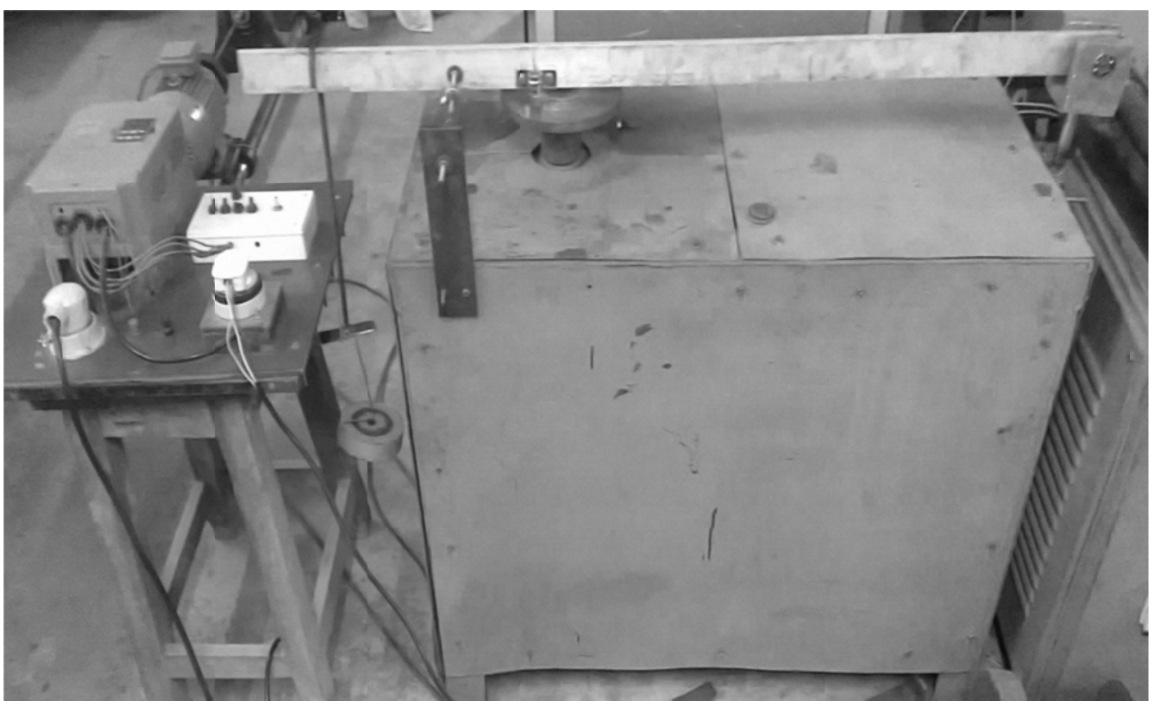

Fig 3.10 Overall experimental setup

## 3.2 Preparation of specimens:

### 3.2.1 Preparation of pellets by pressing operation

The specimen is a ceramic based composite prepared by powder metallurgy process. Following materials are used in powder form to prepare three specimens:

Table 3.1 Materials used in specimen and their melting points

| S.No. | Material | Chemical Formula | Melting Point ($^0C$) |
|---|---|---|---|
| 1 | Copper | Cu | 1083 |
| 2 | Alumina | $Al_2O_3$ | 2072 |
| 3 | Titanium Dioxide | $TiO_2$ | 1843 |

Table 3.2 Compositions (% weight) of three specimens

| Specimen | Cu (% wt) | $Al_2O_3$ (% wt) | $TiO_2$ (% wt) |
|---|---|---|---|
| 1 | 50 | 25 | 25 |
| 2 | 50 | 35 | 15 |
| 3 | 50 | 15 | 35 |

Powders of required weights were taken by help of weighing machine. Powders were put in mortor and mixed properly by help of pestle. 6 – 10 drops of binder (PVA solution) was put in the mixture and again the powders were properly mixed in the mortar till they became dry powder. Powder was collected in a paper. Die and punch were taken to give desired shape to the powder. Die and punch were thoroughly dried by help of acetone solution.

Powder was put inside the die slowly and carefully in order to avoid loss of powder to surrounding. The punch was inserted in the die. The die and punch assembly was kept inside the pressing machine. The pressing machine was set for a load of 4 tons with the dwelling time of 2 minutes. After the pressing operation was completed, the pellet was taken out of die by pressing from opposite direction.

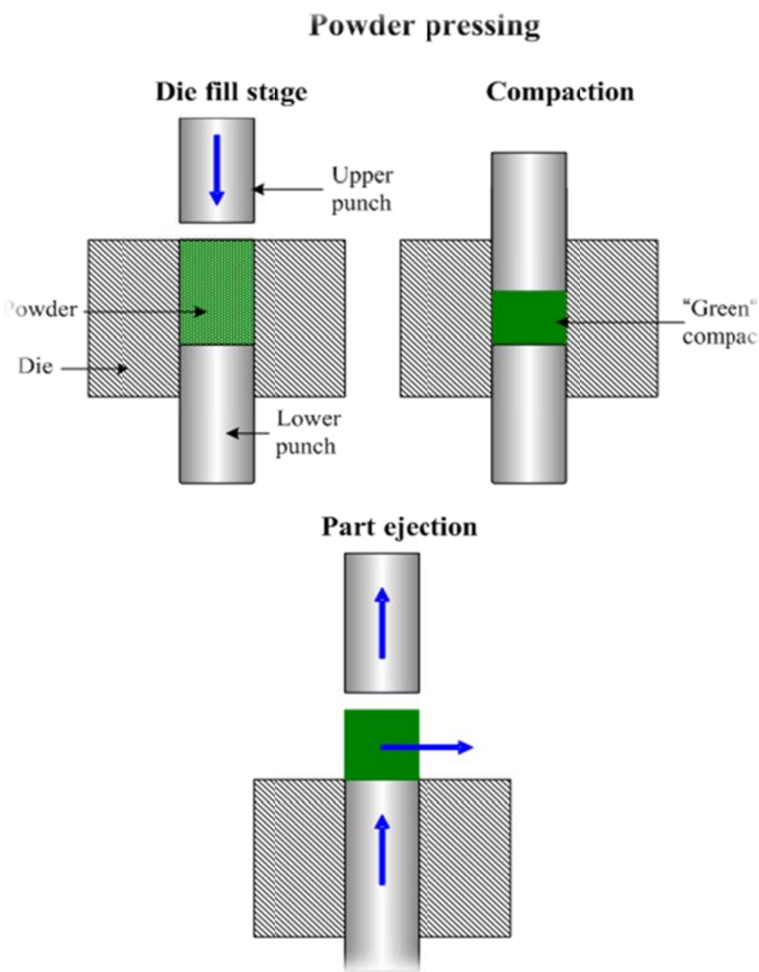


Fig. 3.11 Pressing of powder by help of die and punch

### 3.2.2 Sintering of pellets

The pellet which was produced in above operation was green i.e. weak and can break. So we could not use it directly in our experiment. Before doing the sintering operation, first of all we labeled the three pellets in a suitable way so that the label may not disappear during the sintering process. We took a small silica disc, cleaned it properly and kept the three pellets on the silica disc. Then we kept the whole assembly inside a furnace. We set the furnace for a temperature of 700 $^0$C with a dwelling period of 1 hour. The temperature of furnace starts increasing from 100 $^0$C to 700 $^0$C with a rate of 3 $^0$C per minute. It takes almost 4 hours to reach to the temperature of 700 $^0$C. After the completion of dwelling period the furnace automatically switches off. The furnace cools down from 700 $^0$C to room temperature by natural cooling. This cooling takes about 4 to 5 hours. Slow heating and slow cooling of the specimen is done in order to avoid any damage to the specimen and give strength to the specimen. If we suddenly heat the specimen then rapid evolution of entrapped gases may destroy the specimen. If we cool down the specimen suddenly, then cracks may develop in the specimen due to sudden contraction. After the sintering operation was completed, we got the three specimens ready for conducting the experiment.

## 3.3 Testing for wear rate

Initial weight of the specimen was taken by help of weighing machine. The specimen was clamped to the flat. Load of 20 N was applied on the flat. The specimen was kept in contact with disc. The disc was rotated by help of motor at a given speed for 5 minutes. After 5 minutes, the disc was stopped. The specimen was removed from the clamp. Final weight of the specimen was taken. Weight loss was calculated by using the following formula:

$$\Delta W = IW - FW$$

Where $\Delta W$ is weight loss, $IW$ is initial weight, $FW$ is final weight.

Wear rate in N/m was calculated by using the following formula:

$$WR = \Delta W / d_{sd}$$

Where $WR$ is wear rate, $d_{sd}$ is sliding distance.

Sliding distance was calculated by using the following formula:

$$d_{sd} = 2\pi rNt$$

Where $r$ is radius of wear track, $N$ is sliding speed in RPM (revolutions per minute) of disc, $t$ is time for which disc rotates.

Sliding speed (v) in m/s is calculated by using the following formula:

$$v = 2\pi rN/60$$

Wear track radius was measured and its value was 5.25 cm. Wear rate was calculated for three specimens at three different sliding speeds for 500, 750 and 1000 RPM. Graphs were plotted between wear rate and sliding speed for three specimens.

# Chapter 4

## RESULTS AND DISCUSSION

Table 4.1 Wear rate of specimen 1

| S.No. | Sliding Speed (v) (m/s) | Initial Weight (IW) (gm) | Final Weight (FW) (gm) | Weight Loss ($\Delta W$) (gm) | Sliding Distance ($d_{sd}$) (m) | Wear Rate (WR) (x $10^{-6}$ N/m) |
|---|---|---|---|---|---|---|
| 1 | 2.75 | 8.532 | 8.272 | 0.260 | 824.67 | 3.089 |
| 2 | 4.12 | 8.111 | 7.965 | 0.146 | 1237 | 1.156 |
| 3 | 5.50 | 7.965 | 7.904 | 0.061 | 1649 | 0.362 |

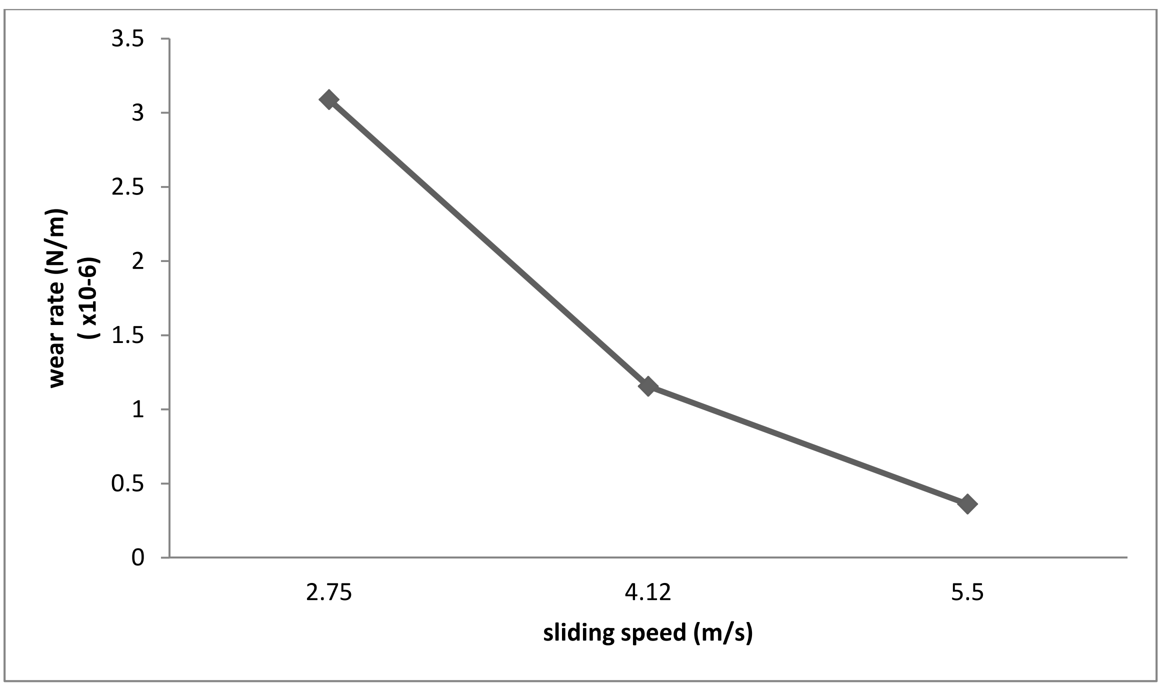


Fig 4.1 Graph between wear rate and sliding speed for specimen 1

Table 4.2 Wear rate of specimen 2

| S.No. | Sliding Speed (v) (m/s) | Initial Weight (IW) (gm) | Final Weight (FW) (gm) | Weight Loss ($\Delta W$) (gm) | Sliding Distance ($d_{sd}$) (m) | Wear Rate (WR) (x $10^{-6}$ N/m) |
|---|---|---|---|---|---|---|
| 1 | 2.75 | 8.194 | 7.330 | 0.864 | 824.67 | 10.267 |
| 2 | 4.12 | 7.217 | 6.626 | 0.591 | 1237 | 4.682 |
| 3 | 5.50 | 6.626 | 6.311 | 0.315 | 1649 | 1.872 |

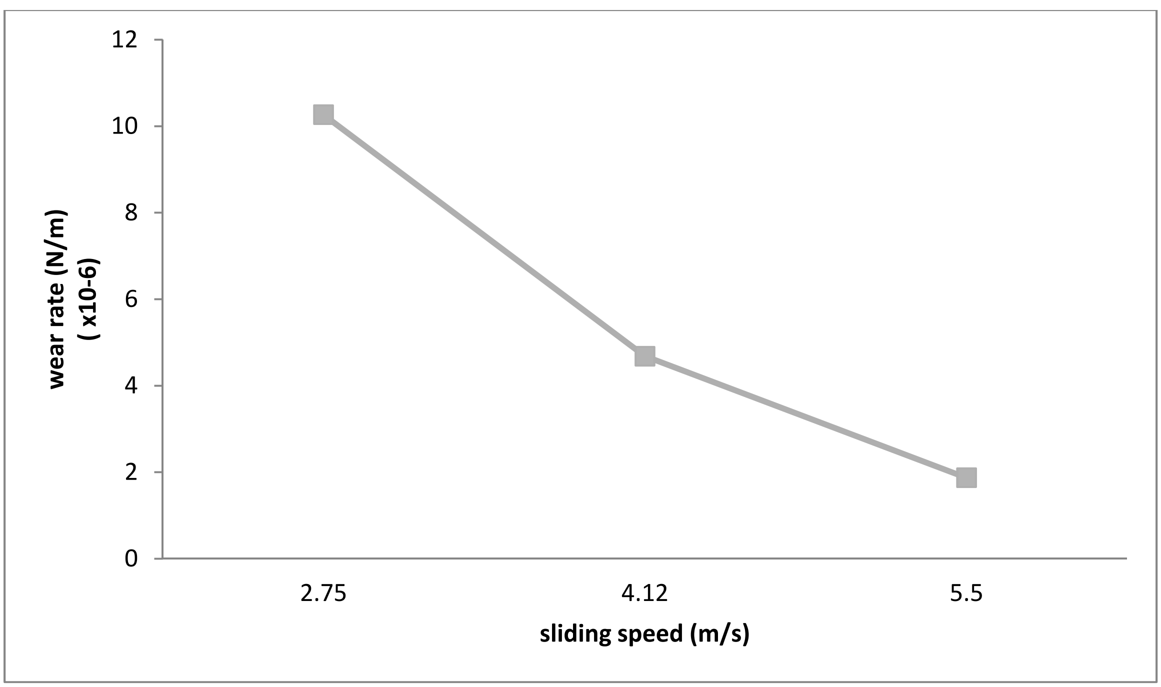


Fig 4.2 Graph between wear rate and sliding speed for specimen 2

Table 4.3 Wear rate of specimen 3

| S.No. | Sliding Speed (v) (m/s) | Initial Weight (IW) (gm) | Final Weight (FW) (gm) | Weight Loss ($\Delta W$) (gm) | Sliding Distance ($d_{sd}$) (m) | Wear Rate (WR) (x $10^{-6}$ N/m) |
|---|---|---|---|---|---|---|
| 1 | 2.75 | 8.552 | 8.120 | 0.432 | 824.67 | 5.133 |
| 2 | 4.12 | 8.120 | 7.883 | 0.237 | 1237 | 1.878 |
| 3 | 5.50 | 7.883 | 7.730 | 0.153 | 1649 | 0.909 |

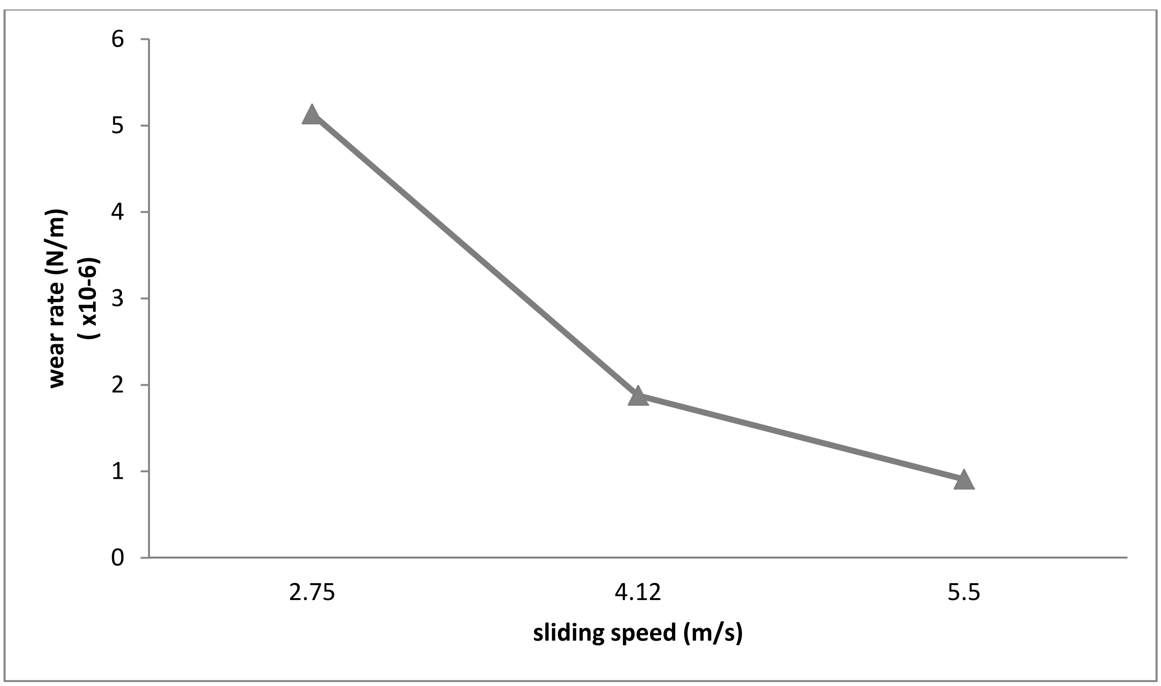


Fig 4.3 Graph between wear rate and sliding speed for specimen 3

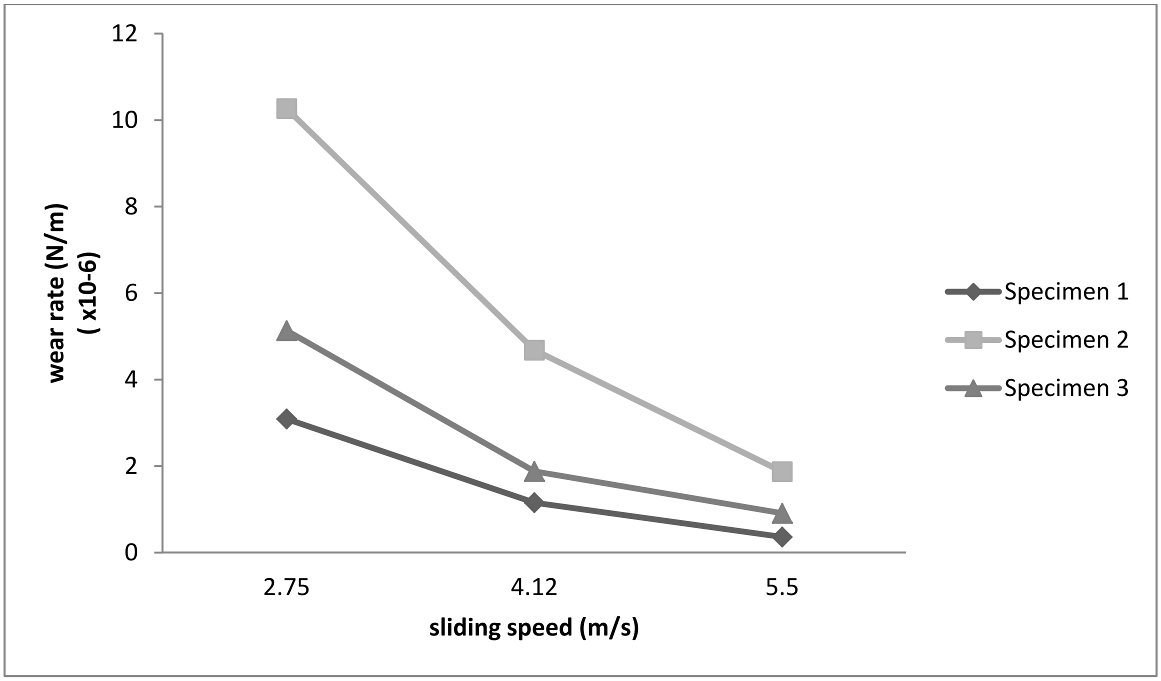


Fig 4.4 Comparison of wear rates for three specimens

From the graphs between wear rate and sliding velocity, we find that as the sliding velocity is increasing, the wear rate is decreasing. The result is supporting the theory that wear rate is inversally proportional to the sliding velocity. Wear rate of specimen 2 was found to be very high. This is due to very high alumina content (35%) which is more than the optimum amount. Due to very high alumina content, there is lack of proper binding and fusion in preparation of composites. Wear rate of specimen 1 was found to be very low as it contained proper combination of alumina(25%) and titanium dioxide(25%). Wear rate of specimen 3 was more than specimen 1 but much less than specimen 2 because the percentage of alumina (15%) is low as compared to optimum amount. Due to very low alumina content, strength of the composite reduces which results in higher wear as compared to specimen 1.

# Chapter 5

## CONCLUSIONS

The present investigation aimed at comparison of wear rates of three composites made from different percentage of copper, alumina and titanium dioxide. The analysis was carried out by fabricating the experimental setup, preparing the three composites and performing the wear test on the specimens. Graphs between wear rate and sliding velocity were plotted for the three specimens and wear rates of three specimens were compared.

It draws the following conclusions:

1. Wear rates of all three specimens decreased with increase in sliding velocity.
2. Specimen 2 having alumina content higher than the optimum amount showed higher wear. Specimen 1 having proper combination of alumina and titanium dioxide showed very low wear rate. Specimen 3 having alumina content lower than optimum amount showed higher wear rate
3. Amount of alumina and titanium dioxide content affects the wear rate. Proper combination of alumina and titanium dioxide results in high wear resistance of the composite.

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